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A ONE-PASS METHOD FOR COUNTING RANGE MEAN PAIR CYCLES FOR FATIG--ETC(U)
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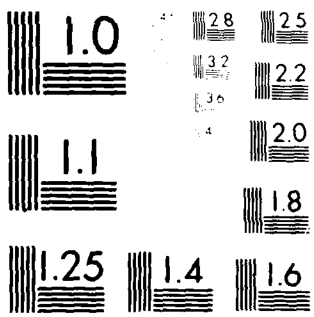

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STRUCTURES NOTE 454

A ONE-PASS METHOD FOR COUNTING RANGE MEAN PAIR CYCLES FOR FATIGUE ANALYSIS

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R. C. FRASER

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A ONE-PASS METHOD FOR COUNTING RANGE MEAN PAIR CYCLES FOR FATIGUE ANALYSIS

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SUMMARY

A one pass method for counting Range Mean Pair cycles is described. The Range Mean Pair Table which is used to represent the data generated by the method is considered with reference to its use in fatigue analysis.

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories, Box 4331, P.O., Melbourne, Victoria, 3001, Australia.

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16. *ABSTRACT*

A one pass method for counting Range Mean Pair cycles is described. The Range Mean Pair Table which is used to represent the data generated by the method is considered with reference to its use in fatigue analysis.

CONTENTS

1. INTRODUCTION

The interpretation of loading environment remains fundamental to many fields of fatigue investigation:

(1) life estimation;
(2) fatigue test load selection;
(3) comparison of load spectra and damage estimates between aircraft, mission type etc.;
(4) load spectra prediction for future aircraft design;
(5) sequence analysis;
(6) crack growth analysis.

Of all the cycle counting methods that exist for this purpose[1-5] the Rainflow and Range Mean Pair methods are deemed the most generally useful from a theoretical point of view because both identify load cycles in terms of the stable cyclic stress-strain behaviour of the material concerned (i.e. turning points are paired that define closed hysteresis loops).[5-9] However, although simpler by definition, the multipass characteristic of existing range mean pair methods has meant that they are less efficient than the one pass rainflow method for use on other than short load records.

The present paper describes a one pass method for counting range mean pair cycles that can be applied to complex load histories of unspecified lengths. The storage of range mean pair data is also discussed with particular attention to the benefits afforded by recording such information in a table. It should be noted that where load is referred to in this paper, strain, normal load factor, stress, bending moment etc., are equally applicable.

2. CYCLE DEFINITION

The basic method for the extraction of range mean pairs from a given load history is given in Reference 2 and is summarized below:

The method is to select and remove from a time ordered list of load maxima and minima (turning points), the adjacent pair having the smallest absolute difference. This is repeated until all possible pairs are removed. Each pair is then considered to constitute the peak and trough of one load cycle for which a mean and alternating load can be determined.

Though extremely simple, this procedure has an obvious limitation: it obtains only one range mean pair for each pass through a given record and thus cannot be efficiently applied to long complex histories in this form.

However, an immediate start to reducing the number of passes required is made when it is seen that this minimum difference definition identifies cycles which constitute perturbations of other larger cycles (i.e. turning points which relate to closed stress-strain hysteresis loops) and that a test based on this may be used to detect more than one range mean pair per pass. From Figure 1 it can be seen that a perturbation test may be expressed so:

for a sequence of four turning points (TP's) denoted $TP(k-3)$, $TP(k-2)$, $TP(k-1)$, $TP(k)$ if

$$|TP(k-3) - TP(k-2)| \geq |TP(k-1) - TP(k-2)| \leqslant |TP(k) - TP(k-1)| \qquad \text{— equation (A)}$$

the cycle $TP(k-2)$, $TP(k-1)$ constitutes a range mean pair. This will hitherto be referred to as the 'four point test'.

By advancing through the load history and considering four turning points at a time, using (A), the number of range mean pairs obtained per pass is increased although several passes are still required to process the entire load history. The refinement necessary to obtain complete processing in a single pass is realized when (A) is used repetitively as follows:

As each turning point is passed it is loaded into a turning point stack and equation (A) used to test if it identifies the previous two turning points in the stack as a range mean pair.

If a range mean pair is not detected the next turning point in the load history is loaded into the stack and the process repeated until a range mean pair is found. When this occurs the range mean pair turning points are removed from the stack, the gap closed and equation (A) used again to detect as many range mean pairs as possible e.g. if the turning point $TP(k)$ identifies the turning points $[TP(k-1), TP(k-2)]$ as a range mean pair it may similarly detect the turning points $[TP(k-3), TP(k-4)]$ as a range mean pair and so on. The sequence of points for which this repetitive pairing occurs is shown in Figure 2.

In this way cycle counting proceeds through the load history with the turning point stack being progressively loaded and emptied.

In the preceeding it has been shown that a four point test can be used to process a load history in a single pass. However, it can be demonstrated that the single pass characteristic itself is conducive to a further improvement in the actual test for a range mean pair.

Consider Figure 3 where the second sequence of Figure 1 has been reproduced. The four point test (equation A) would pair $TP(k-1)$, $TP(k-2)$ as before. Now suppose that the same situation exists except that the $TP(k-3)$ is in a different position such as in Figure 3*b*. In this instance the one pass four point procedure would not reach $TP(k)$ with the given sequence undisturbed since it would have removed the pair $TP(k-3)$, $TP(k-2)$ when it reached $TP(k-1)$. Thus the turning point $TP(k-3)$ can only lie where it is depicted in Figure 3*a* (i.e. below the load values of $TP(k-2)$ and $TP(k-1)$) if it is to remain in the history unpaired when the four point one pass method reaches $TP(k)$. Hence the use of the fourth point, $TP(k-3)$ is unnecessary in this situation and only the right hand portion of equation (A) need be used as the range pair test (hereafter called the three point test). The same argument applies to the mirror image of Figure 3 if "below" is replaced by "above" so that the three point test suffices for all cases. The decision to use either the four point or three point test in the one pass method is considered below.

3. END EFFECTS

The end effect problem is basically due to the fact that every practical load history is of a finite length and thus there must exist in every load history turning points which cannot be identified as perturbations of larger cycles simply because the turning points of those larger cycles do not occur in the given record. Hence, every range mean pair method must leave at the end of processing some unpaired 'residual' turning points.

Consider Figure 6*a* where load histories (*a*) to (*h*) are depicted. Because the prior and subsequent load sequences for each history are unknown no range mean pair can be found in any of them (i.e. no corresponding closed stress strain hysteresis loop can be firmly identified without more information at the ends of the given sequences) and thus the conservative strategy of pairing maximum peak to minimum trough is usually adopted.

After the last turning point of the load history has been loaded into the TP stack and either the three or four point test used to check if it defines any range mean pairs, it and possibly other TP's representing those discussed above, will remain unpaired in the TP stack. (It should be noted that the number of TP's involved is usually very small, often only two or three, and that sequences (*a*) to (*d*) represent the residuals possible after a three point test has been used while for the four point test, (*e*) to (*h*) are also possible.)

When a four point test is used in the one pass procedure the turning point stack is emptied using the minimum trough to maximum peak method as already outlined, however when a three point test is in use, it is possible to unload the residual TP's in the stack without changing to a different pairing process. If one considers sequences (*a*) to (*c*) of Figure 6*a* again, it can be seen that pairing of the turning points in the stack at the end of the load history can be accomplished by loading a large 'dummy' turning point into the end of stack and using the three point test as before to pair right to left as shown in Figure 2. When the last TP is a peak the 'dummy' TP is a large +ve number and vice versa for a trough (e.g. + or − 10^{30}). This may necessitate further further adjustments as described below.

The advantages in using the three point test for both the main processing and the end effect correction are that the computer program written to implement the method is short and simple and the execution time is similarly short even on long load histories. The disadvantage is that

in some instances the pairing of the end effect sequence is unconservative i.e. minimum trough to maximum peak pairing does not occur.

When a load history contains an odd number of turning points one TP will obviously remain after pairing. When the four point test is used this TP will be the peak or trough closest to the mean of the 'residual' sequence, (e.g. one of the turning points at either end of sequences (*e*) to (*h*) in Figure 6*a*) and when the three point test is used it will be the largest peak or smallest trough in the load history. In the former instance the damage contribution is slight and can usually be ignored, however in the latter case *the damage contribution may be significant* enough to warrant adding a mean load TP to the TP stack to ensure its pairing (this is sometimes called closing the sequence). When this nominal TP is used it is added to the stack before the dummy to obtain conservative pairing.

For a data sequence consisting of more than one block (flight) two alternatives exist for the application of the end effect correction. It may be used at the end of each block or at the end of the entire sequence. The choice of either alternative is basically a philosophical one, and may depend on many factors such as the accuracy of the data record in representing local loading conditions e.g. for a sequence of many flights of data over which there was little change in structural condition (no crack initiation or crack growth etc.) the latter alternative may be chosen. When the opposite is true it may be considered that applying the end effect correction at the end of each block results in some consistency in the results (i.e. turning points are paired which occur under similar conditions). The treatment of the 'odd' number turning point as discussed in the previous paragraph is also relevant here as is obvious that applying the end effect correction at the end of the entire sequence of blocks will result in only one possible 'odd' number turning point.

One other end effect requires some consideration. Should the first and last points in the record be considered as turning points? e.g. if Figure 7 represents an in-service load sequence it may be argued that points *A* and *B* constitute turning points though the influence of points *A* and *B* on the pairing is small in all cases except where the data record is very short. One convenient method of 'closing' a sequence uses point *B* as follows: if the turning point stack contains an odd number of turning points after the last true turning point has been loaded and used to detect as many range mean pairs as possible, then point *B* is considered a turning point and is loaded into the stack and used to test for range mean pairs. The pairing of the residual history proceeds as before for the specific test used. When the reverse is true and the stack contains an even number of turning points after the last true turning point has been considered then point B is not used and end correction proceeds.

Now consider the pairs obtained when the three point one pass procedure is used to cycle count each of the turning point sequences shown in Figure 6*a* using the 'nominal' and 'dummy' TP's as relevant. The results are shown in Figure 6*b* and for all sequences baring *c*, *g*, *f* max-peak to min-trough type pairing occurs. The influence of the less conservative pairing demonstrated in sequences *c*, *g*, *f* on fatigue damage estimates is small for all but short load records. In the latter case a four point test is substituted for a three point test and a max-peak to min-trough pairing method used to pair off the *g*, *e*, *f*, *h* type sequences that will remain when all range mean pairs have been removed.

The complete one pass counting method obtained by correcting the basic procedure for end effects as above is shown schematically in Figure 8.

4. RANGE MEAN PAIR TABLE

Because of the large amount of RMP data that can be generated from long data records a means of recording such data efficiently is desirable. The range mean pair table fulfils this requirement and also provides a form which, as is shown in the next section, proves useful in many areas of fatigue analysis.

The table is simply a half array with axes of peak and trough load obtained by grouping the range mean pairs obtained from the load history into a number of cells.

Suppose that the maximum possible load existing in a given record will not exceed the value L_{max} and the minimum possible load will not be less than L_{min}. Then dividing this load range into *n* levels to give the level size LS, provides a basis for grouping the range mean pairs. Consider Figure 9 where the range mean pair of load $x1$ to load $x2$ is shown to be represented

on the basis of levels by the range mean pair of level $(i+1)$ to level $(i+5)$. Hence the cell in the range mean pair table corresponding to this range mean pair would record a count of one. At the end of processing of a load history all range mean pairs whose trough and peak were similarly in levels $(i+1)$ and $(i+5)$ respectively would be represented in the table as a corresponding count in the same cell (Fig. 10). Similarly all other range mean pairs generated by the counting method would be grouped into their respective cells in the range mean pair table.

When the information stored in the range mean pair table is required, the load data is calculated using the minimum load (L_{min}) and level size (LS) values e.g. the counts shown in Figure 10 represent range mean pairs from a trough of load $L_{min}+(i+1-0{\cdot}5)$LS to a peak of load $L_{min}+(i+5-0{\cdot}5)$LS. The mean and alternating loads can then be calculated from these values accordingly. It should be noted that:

(i) The leading diagonal of the range mean pair table represents "degenerate" range mean pairs i.e. range mean pairs for which both the peak and trough lie within the one level. As the alternating load for these grouped range mean pairs is zero when determined by assigning load values to their peaks and troughs as above, they are not usually used in a fatigue damage calculation based on the range mean pair table (the S–N data used will determine if the range mean pair data contained in this diagonal should be included in the damage calculation in which case a conservative estimate of alternating load such as LS/4 could be used.)

(ii) Diagonals parallel to the leading diagonal (down left to right) represent range mean pairs with the same alternating load.

(iii) Conversely, diagonals in the opposite sense (up left to right) represent range mean pairs with the same mean load value. (Fig. 11).

(iv) The range mean pair table shown in Figure 10 as a half array can also be configured as a vector to save computer storage space.

(v) The number of levels into which the load range is divided determines the accuracy of the table in recording the range mean pairs discussed below.

In Figure 10 range mean pairs with troughs in level $i+1$ and peaks in level $i+5$ are shown recorded in the range mean pair table by the respective number of counts K. These range mean pairs are assumed to be distributed within the given levels such that their mean value in load terms can be taken to be the mean value of those levels. Thus the smaller the level size used (i.e. the larger the number of levels) the smaller the error inherent in this assumption. A typical example of the effect of the number of levels chosen for the table on its accuracy is illustrated in Figure 12 where fatigue damage estimated for a structural component has been calculated from the individual range mean pairs of an in service record and compared with that obtained from range mean pair tables of the same data. The 'zig-zagging' effect within the envelope shown in Figure 12 is a result of the range mean pairs suddenly crossing level boundaries as the number of levels within the tables is changed. Figure 12 also indicates the rapid convergence of damage estimates obtained from the tables to the correct value as the number of levels is increased. Experience has shown thirty or more levels to be preferable for range mean pair table damage estimates though sufficient accuracy is often obtained with as few as ten levels. The table's accuracy can be checked by comparing damage calculated at processing time with that obtained from the completed table.

5. RANGE MEAN PAIR TABLE USE

The range mean pair table is used primarily for fatigue life estimation although it is useful in some of the other areas of fatigue interest given in the introduction.

Fatigue damage estimates can be obtained from the data contained in the table by calculating the damage attributable to each cell on the basis of its mean and alternating load and on the counts recorded therein, (degenerate diagonal cells are ignored) and summing in accordance with Miner's rule.

The range mean pair table also facilitates damage density calculations because of the way in which it presents ordered sets of mean and alternating load. (Fig. 11).

Fatigue meter counts of normal load factor form the basis of many in-service fatigue damage estimates. These counts can be simulated from range mean pair tables of vertical acceleration or related parameters. For a fatigue meter of x thresholds (where x is typically 8) the counts

recorded for each threshold can be found by summing all range mean pair counts within the area of the table bounded by those levels which encompass the corresponding 'cocking' and 'firing' levels, denoted respectively L_c and L_f. This is demonstrated in Figure 13 where the smallest range mean pairs capable of registering a count for the two types of thresholds ($L_f > L_c$ and $L_f < L_c$ respectively) are shown. Thus for either threshold type a range mean pair having a peak in a higher level and a trough in a lower level than the minimum required would also register a count for that threshold. Hence the total number of counts registered for the given fatigue meter threshold is the sum of all such range mean pairs in the table, i.e. the sum of all range mean pairs in the table bounded by the respective 'cocking' and 'firing' levels.

For a fatigue meter that 'fires' all thresholds at the same value (typically 1 g) the summation can be performed cumulatively. This is illustrated in Figure 14 for positive 'cocking' values. The same procedure is used to sum vertically for negative values.

Where the objective is not to simulate the performance of a particular fatigue meter but to provide data for spectra a slight modification is utilized. From Figure 15*a* summing proceeds cumulatively using every level in the range mean pair table (in effect representing a fatigue meter of *n* thresholds and variable 'cocking' and 'firing' values). This produces counts for spectra as shown in Figure 15*b*. Spectra for parameters other than normal load factor are produced in the same way as above from their respective range mean pair tables.

Two examples demonstrating the application of the one pass range mean pair method are given in the Appendix.

6. CONCLUSION

A method for counting range mean pair cycles has been described that can be used to process a load history of any unknown length in a single pass. The obvious benefits of this method lie in its simple implementation, speed and application to unconditioned data, (i.e. no adjustment of a load history such as setting maximum load first etc. is required).

The range mean pair table which records data two dimensionally has also been discussed with particular attention to the manner in which is can be used to enhance the capabilities of the one pass method to process and store very large amounts of data.

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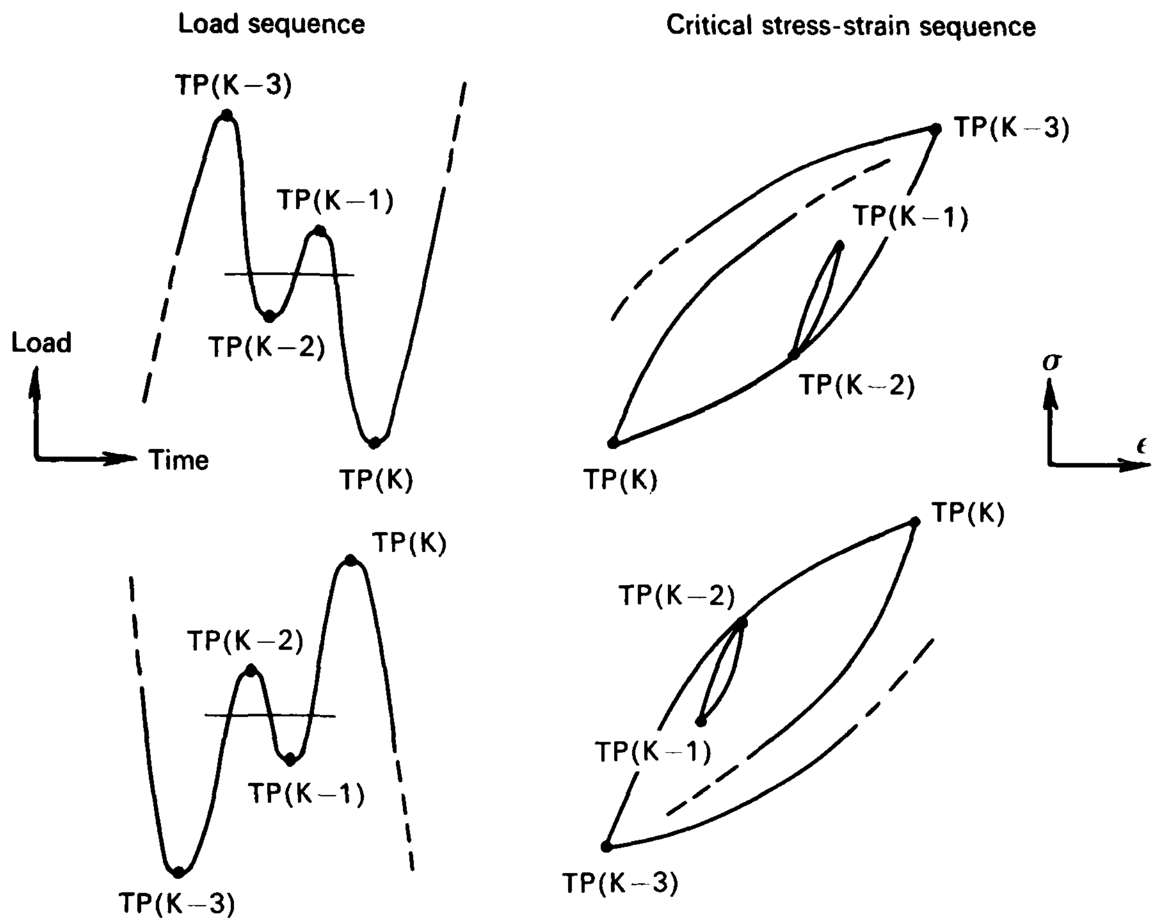
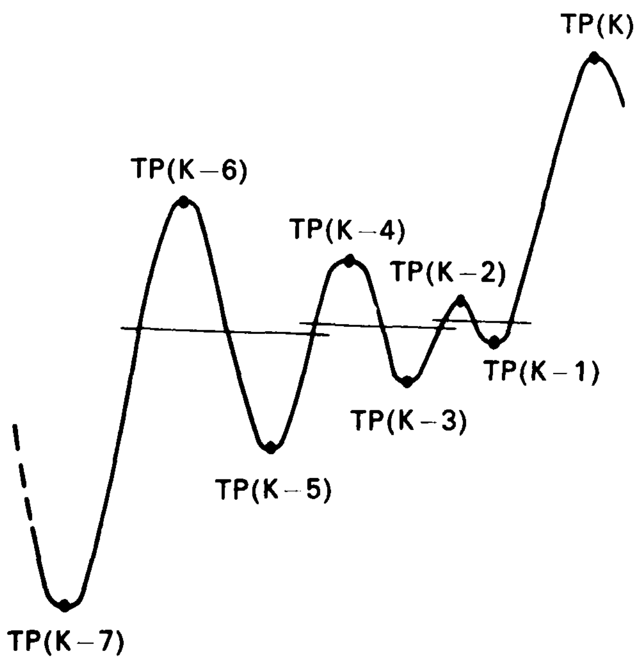


FIG. 1: THE PERTURBATION DEFINITION OF THE RANGE MEAN PAIR AND ITS CORRESPONDENCE TO STABLE CYCLIC STRESS-STRAIN HYSTERESIS LOOPS



When the one-pass method reaches TP(K) with the contents of the turning point stack represented as shown:
TP(K) and TP(K−3) will detect the RMP TP(K−1), TP(K−2)
TP(K) and TP(K−5) will detect the RMP TP(K−3), TP(K−4)
TP(K) and TP(K−7) will detect the RMP TP(K−5), TP(K−6)
i.e.: Repetitive firing of RMP's can occur whenever a RMP test is used.

FIG. 2: REPETITIVE PAIRING OF RANGE MEAN PAIR CYCLES BY A ONE-PASS METHOD

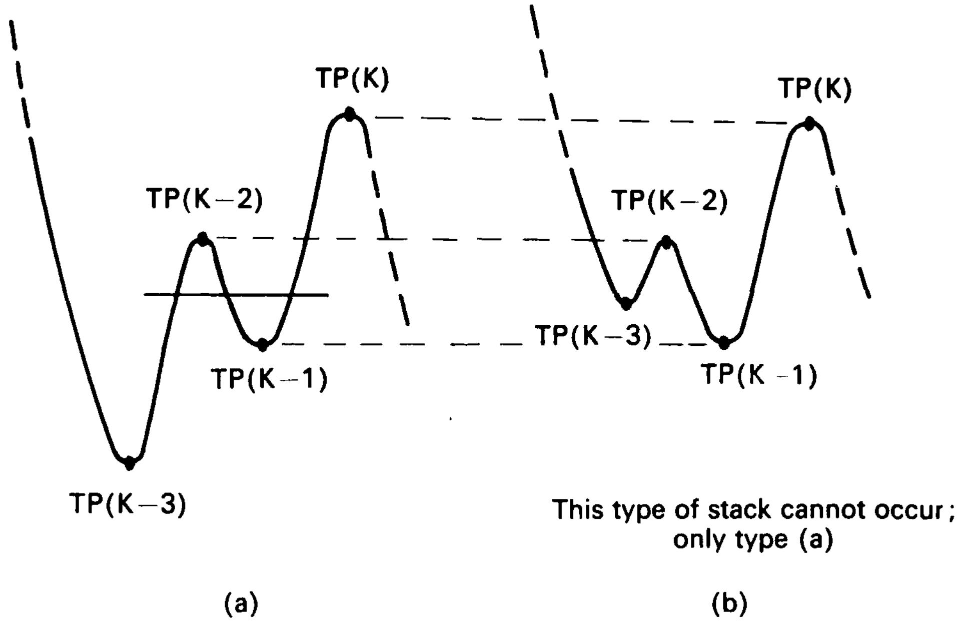


FIG. 3: DERIVATION OF THE THREE-POINT TEST—
SEE CYCLE DEFINITION

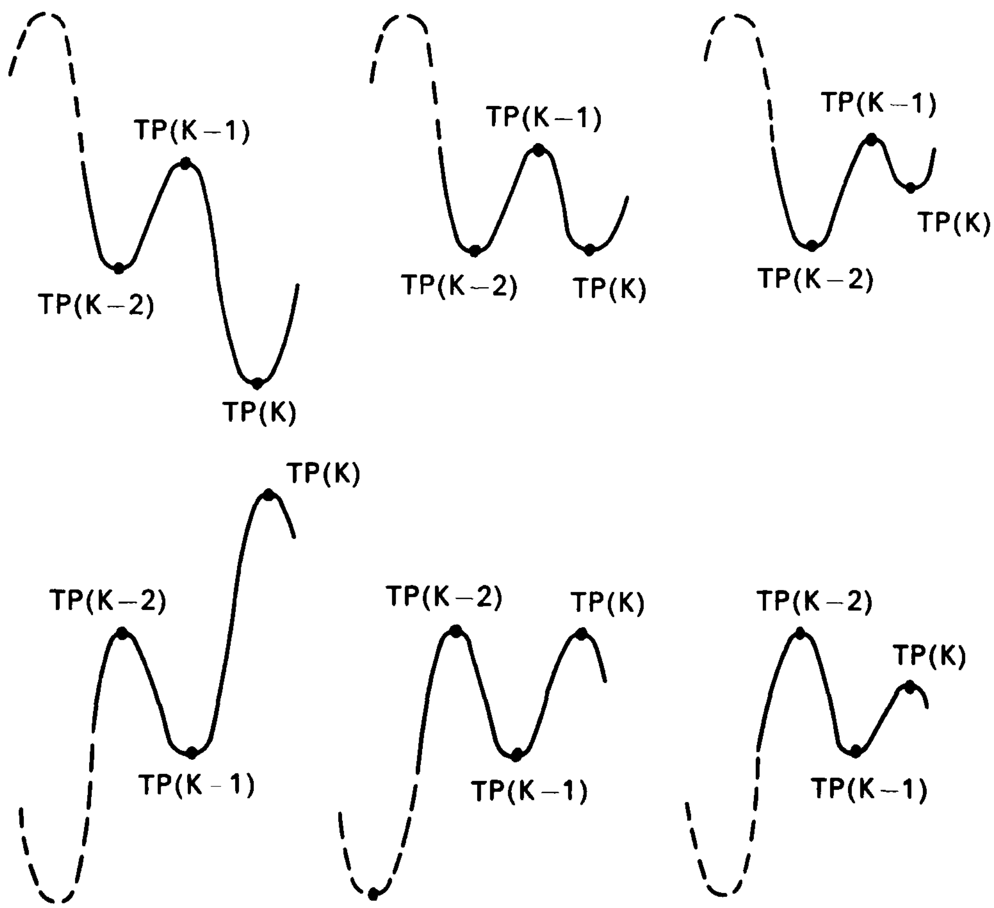
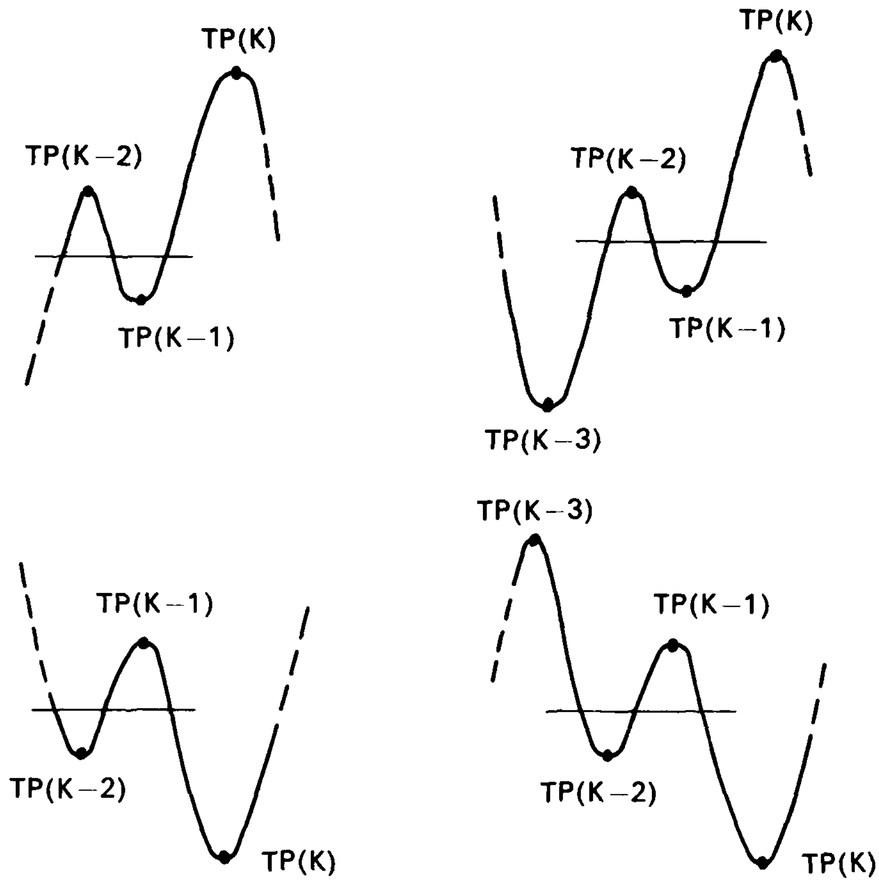


FIG. 4: THREE-POINT SEQUENCES



(a) The three-point test

(b) The four-point test

$$|TP(K-1) - TP(K-2)| \leq |TP(K) - TP(K-1)|$$

$$|TP(K-3) - TP(K-2)| \geq |TP(K-1) - TP(K-2)| \leq |TP(K) - TP(K-1)|$$

FIG. 5: THE THREE-POINT AND FOUR-POINT RANGE MEAN PAIR TESTS

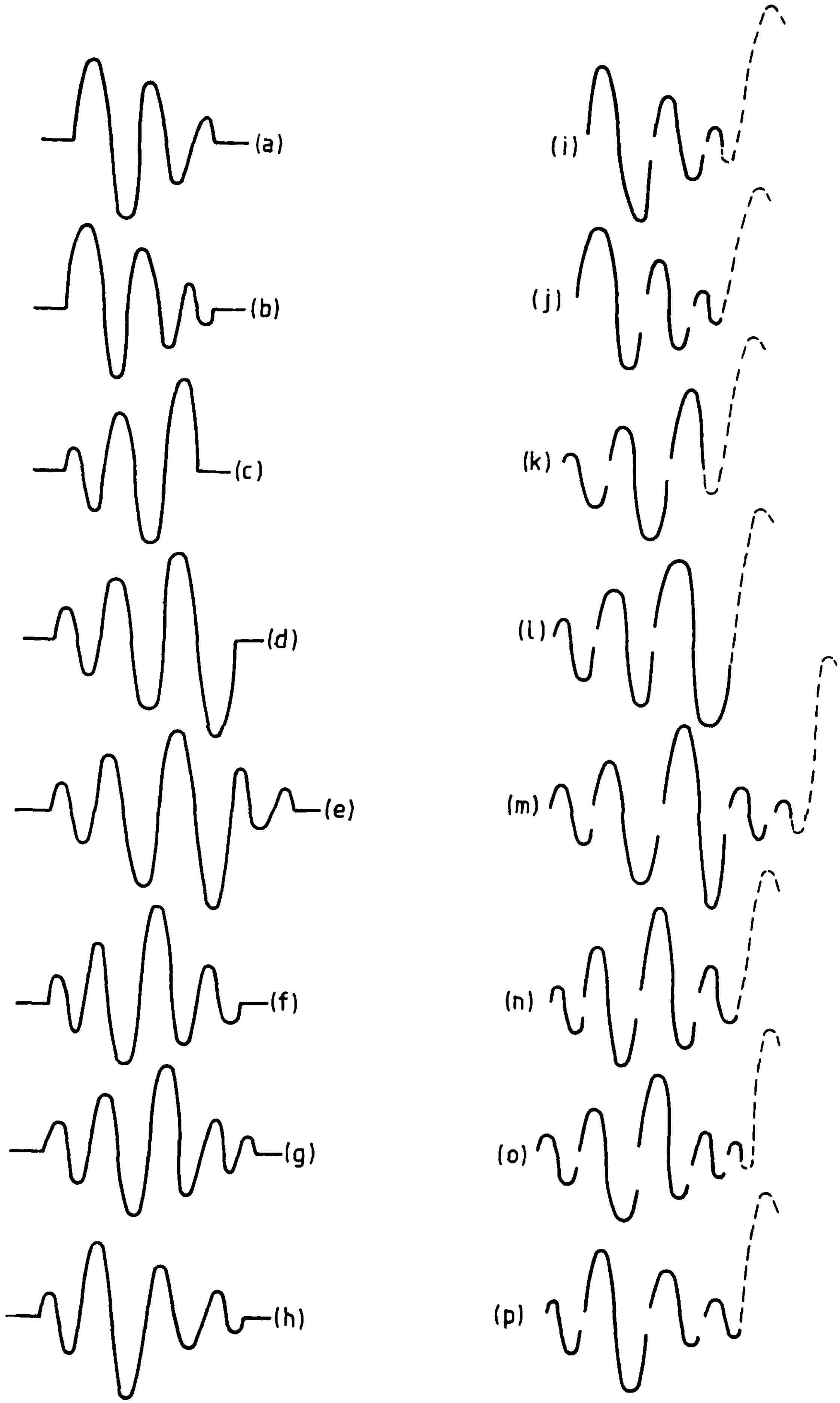
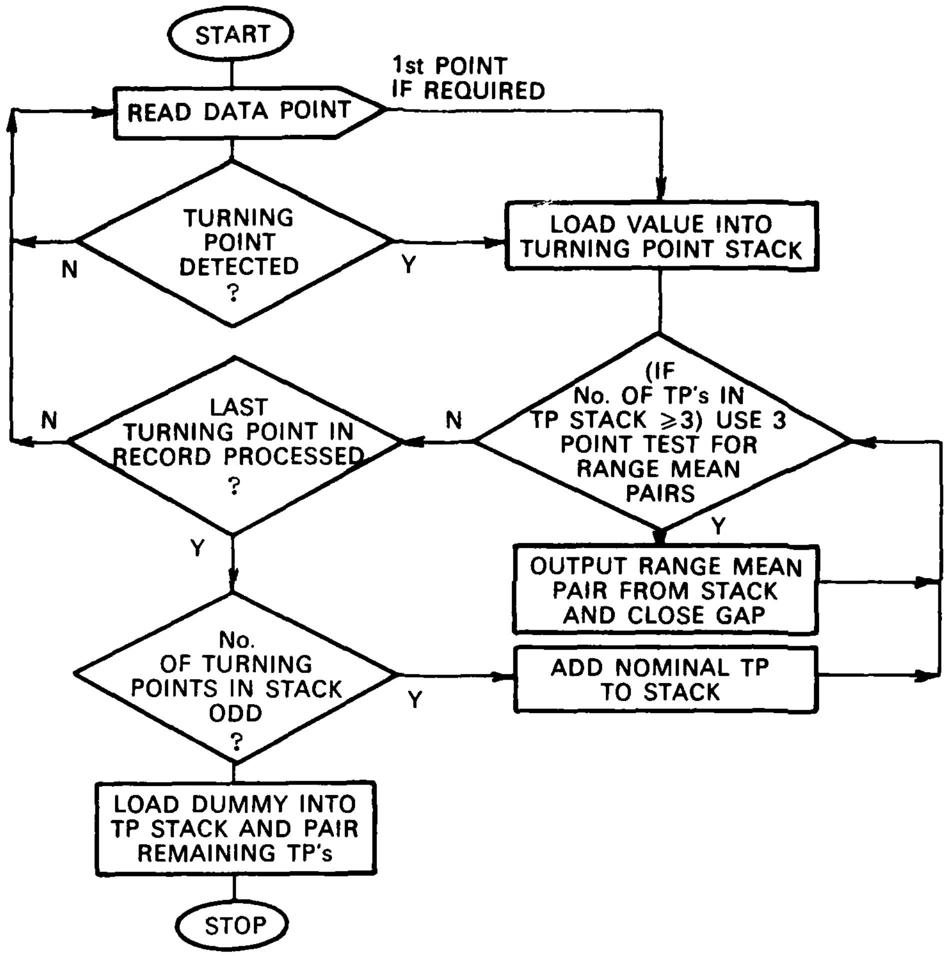


FIG. 6: ILL-DEFINED RANGE MEAN PAIR SEQUENCES WITH THREE-POINT TEST PAIRING RESULTS

FIG. 7: INITIAL AND FINAL TURNING POINTS



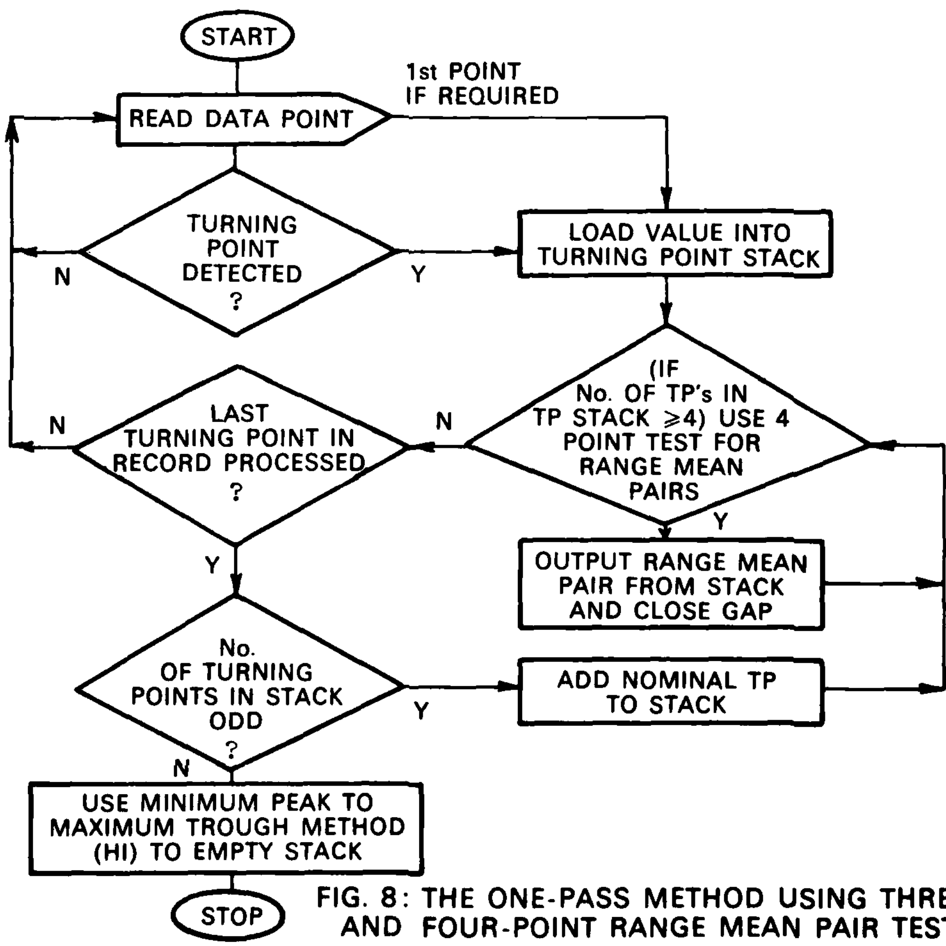


FIG. 8: THE ONE-PASS METHOD USING THREE- AND FOUR-POINT RANGE MEAN PAIR TESTS

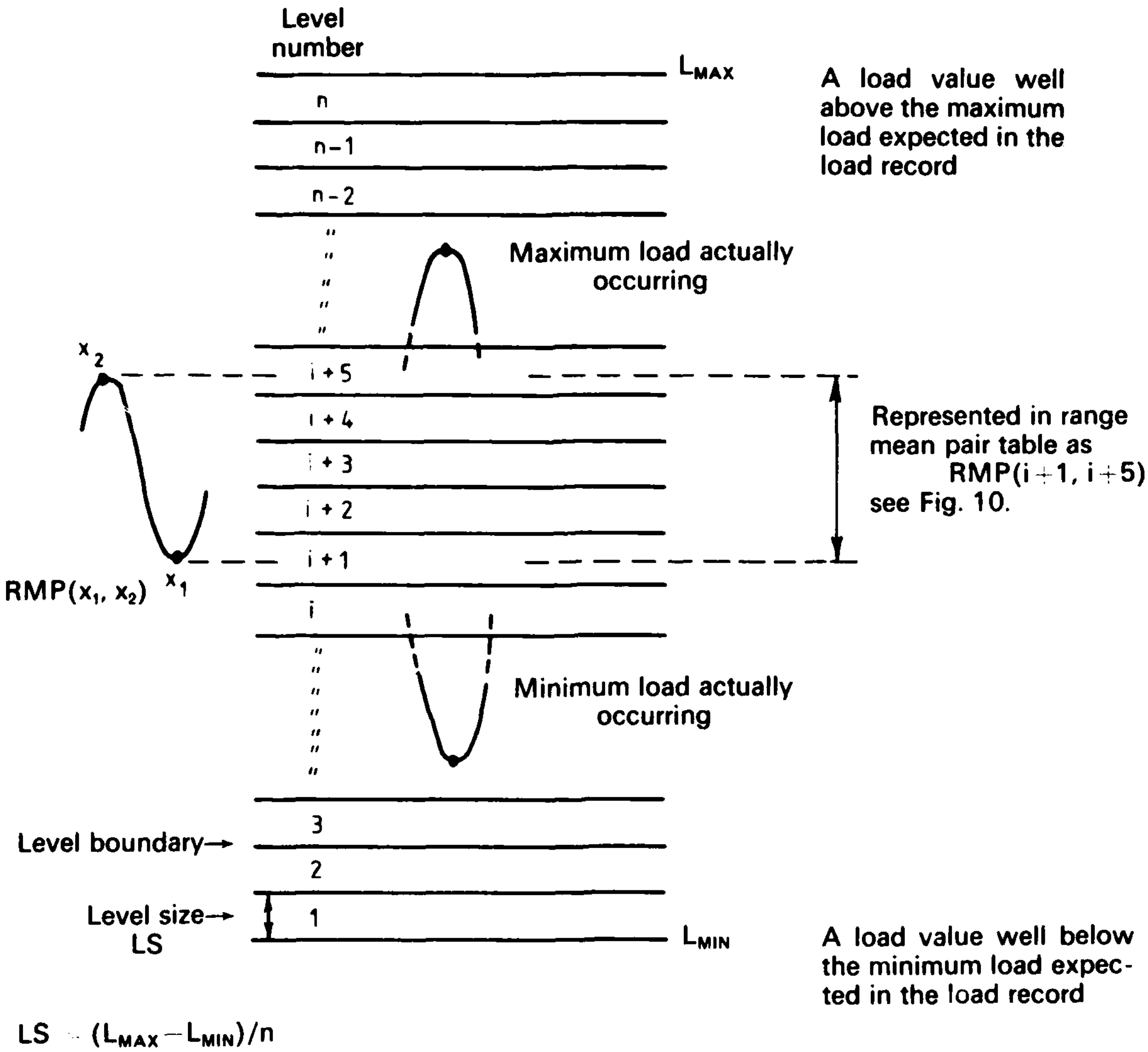


FIG. 9: TABLE "GROUPING" OF RANGE MEAN PAIRS

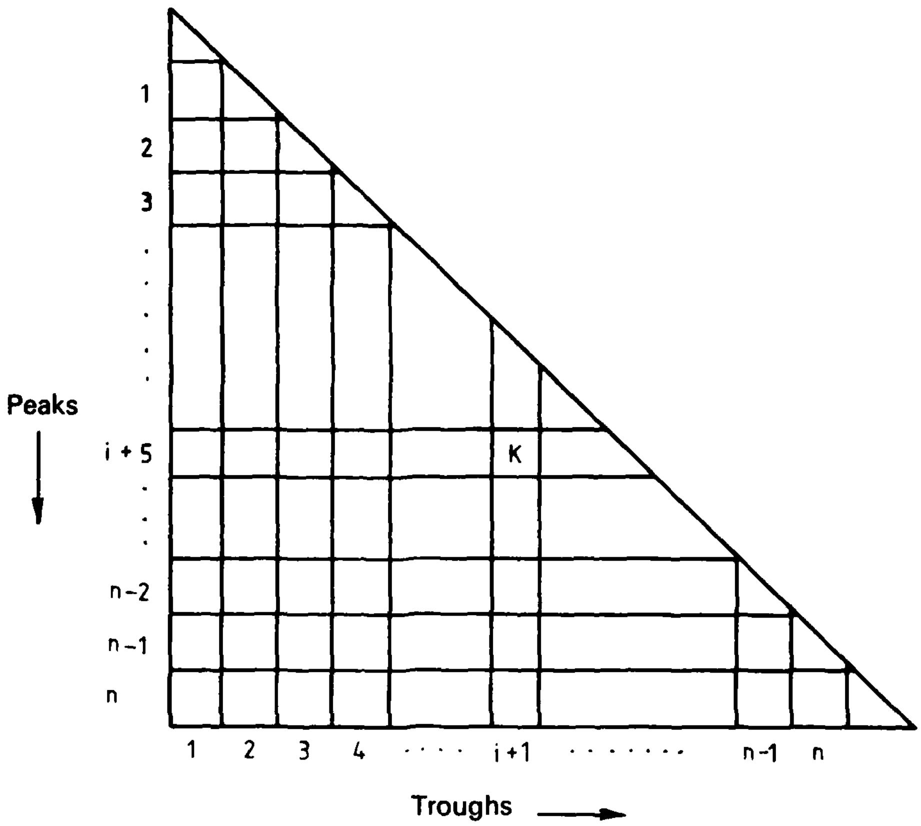


FIG. 10: THE RANGE MEAN PAIR TABLE

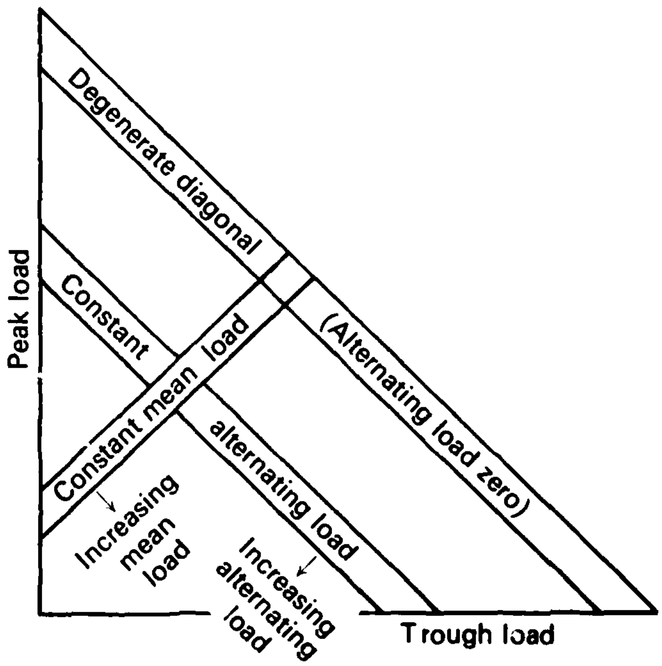


FIG. 11: RANGE MEAN PAIR TABLE CHARACTERISTICS

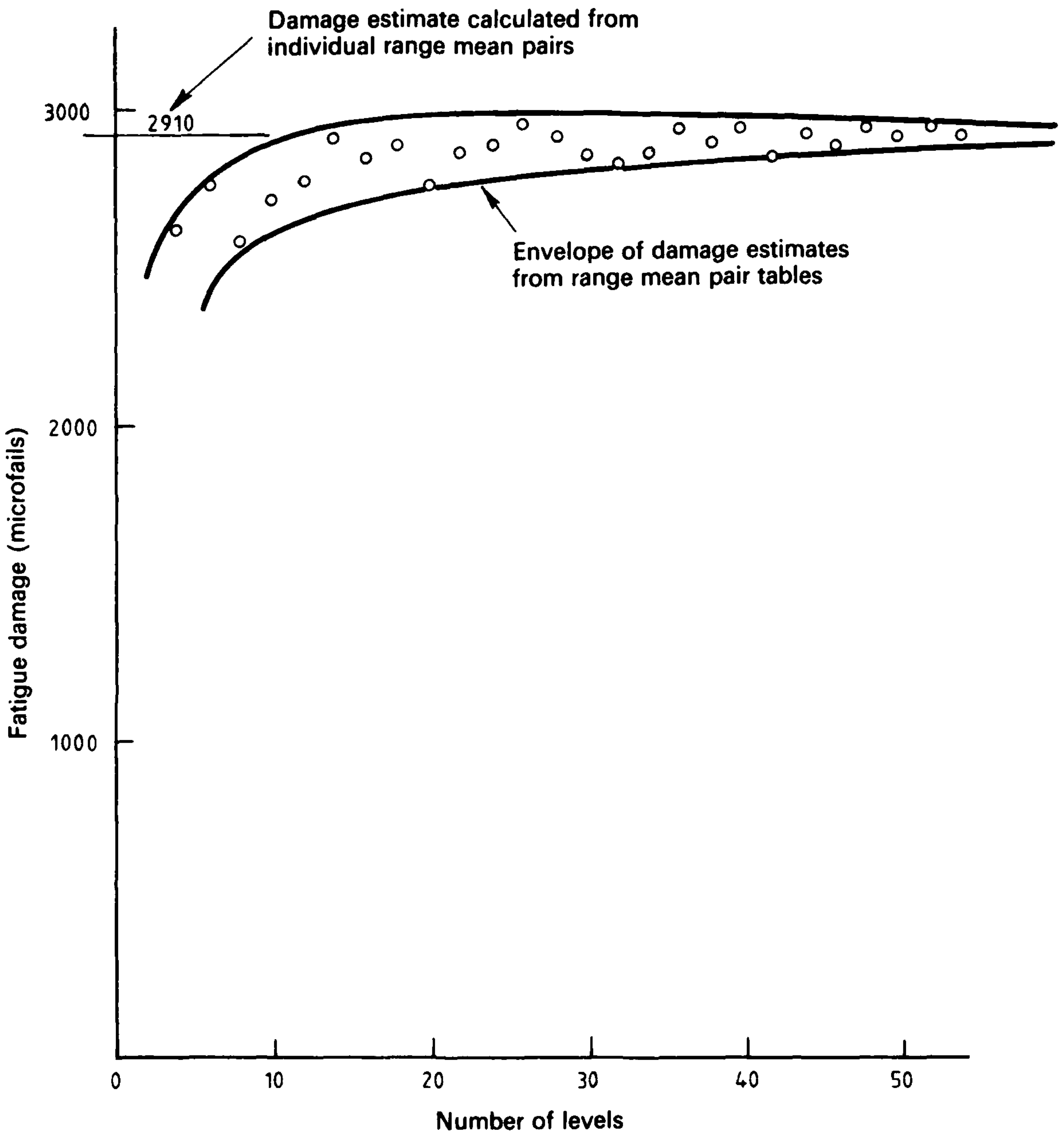


FIG. 12: EFFECT OF NUMBER OF LEVELS ON ACCURACY OF THE RANGE MEAN PAIR TABLE

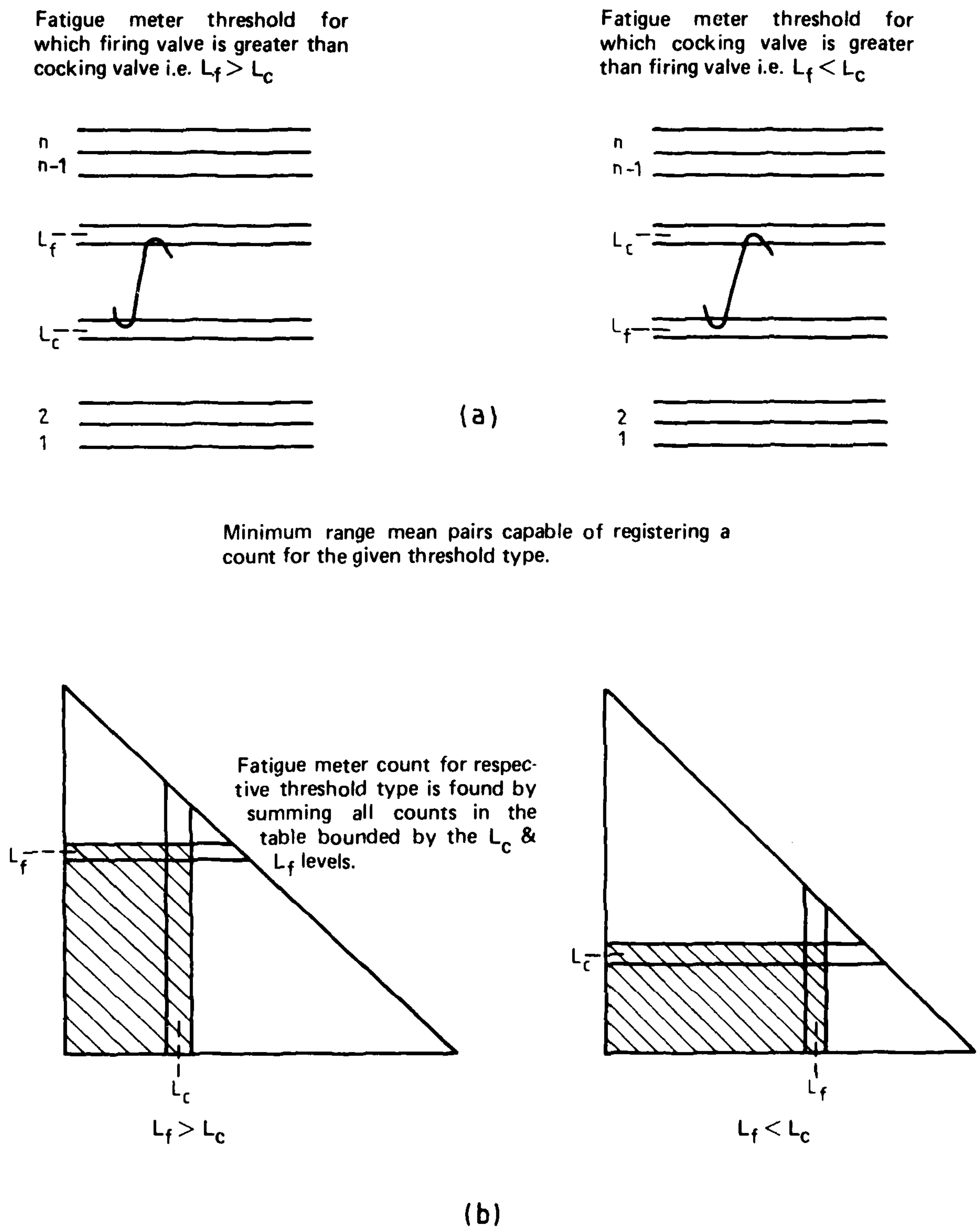


FIG. 13 – GENERATING FATIGUE METER COUNTS FROM THE RANGE MEAN PAIR TABLE.

$$FMC_j = FMC_{j-1} + \sum_{i=Lc_{j-1}+1}^{i=Lc_j} Si \qquad SLc_j$$

$$FMC_2 = FMC_1 + \sum_{i=Lc_1+1}^{i=Lc_2} Si \qquad SLc_2$$

$$FMC_1 = \sum_{i=n}^{i=Lc_1} Si \qquad SLc_1$$

S_{n-1}

S_n

Fatigue Meter Counts — Row sum

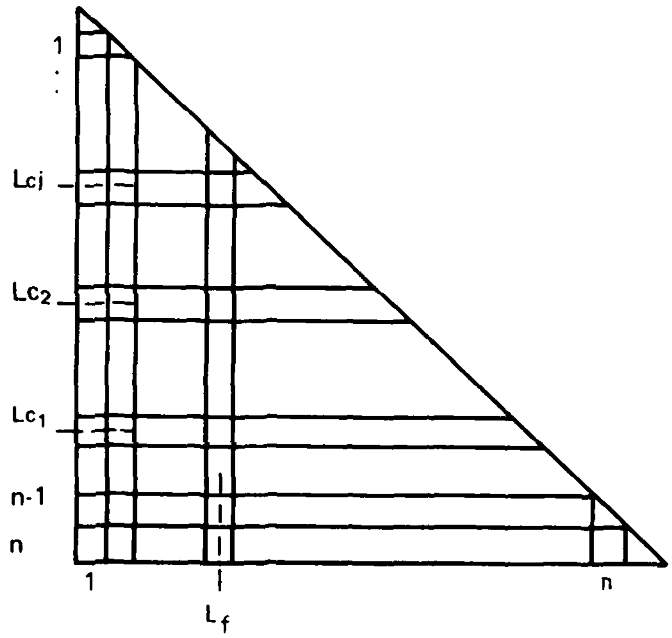


FIG. 14 – CUMULATIVE COUNTING FOR FATIGUE METER WITH j 'COCKING' VALUES AND A SINGLE 'FIRING' VALUE.

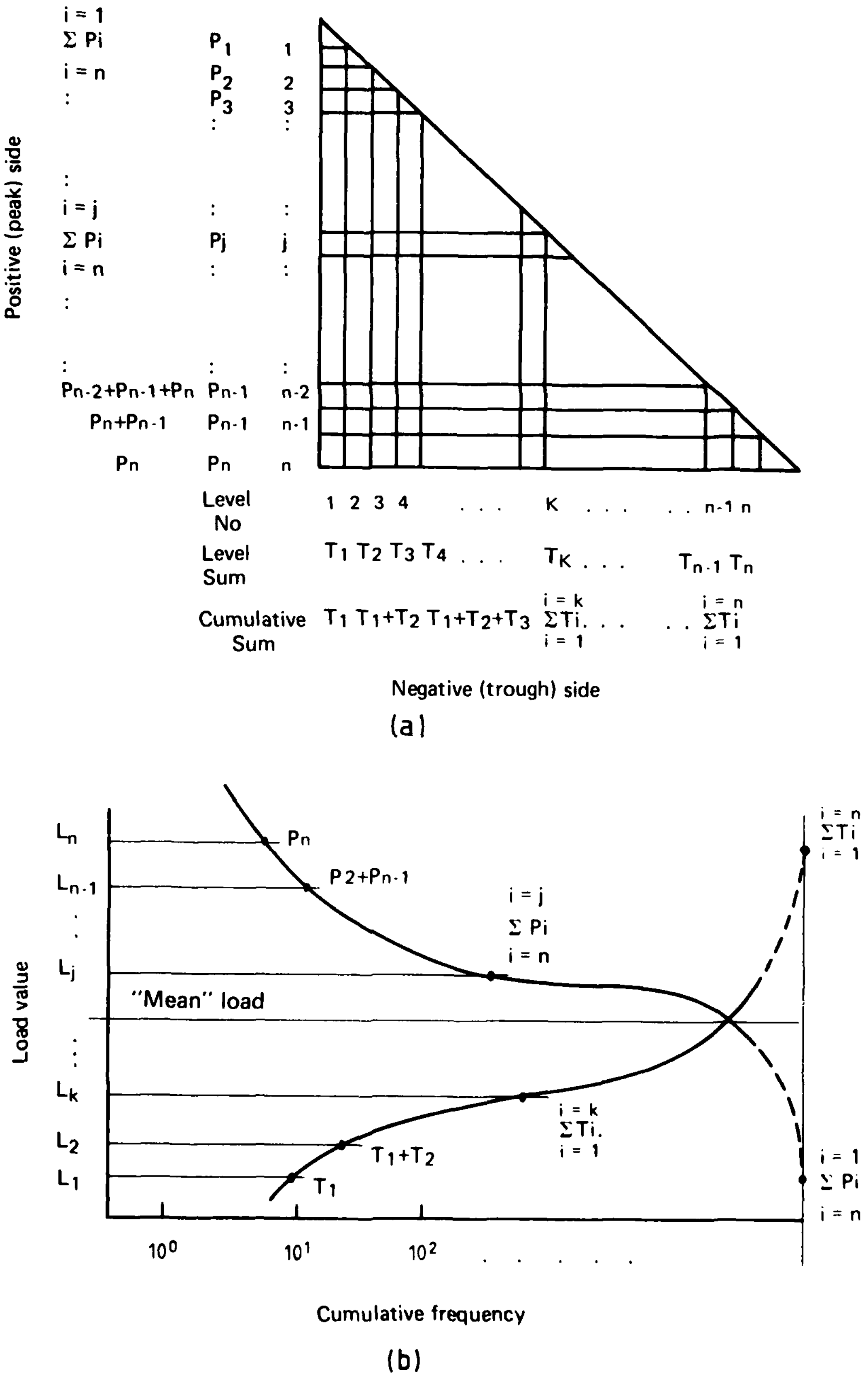


FIG. 15 – PRODUCING SPECTRA FROM RANGE MEAN PAIR TABLES.

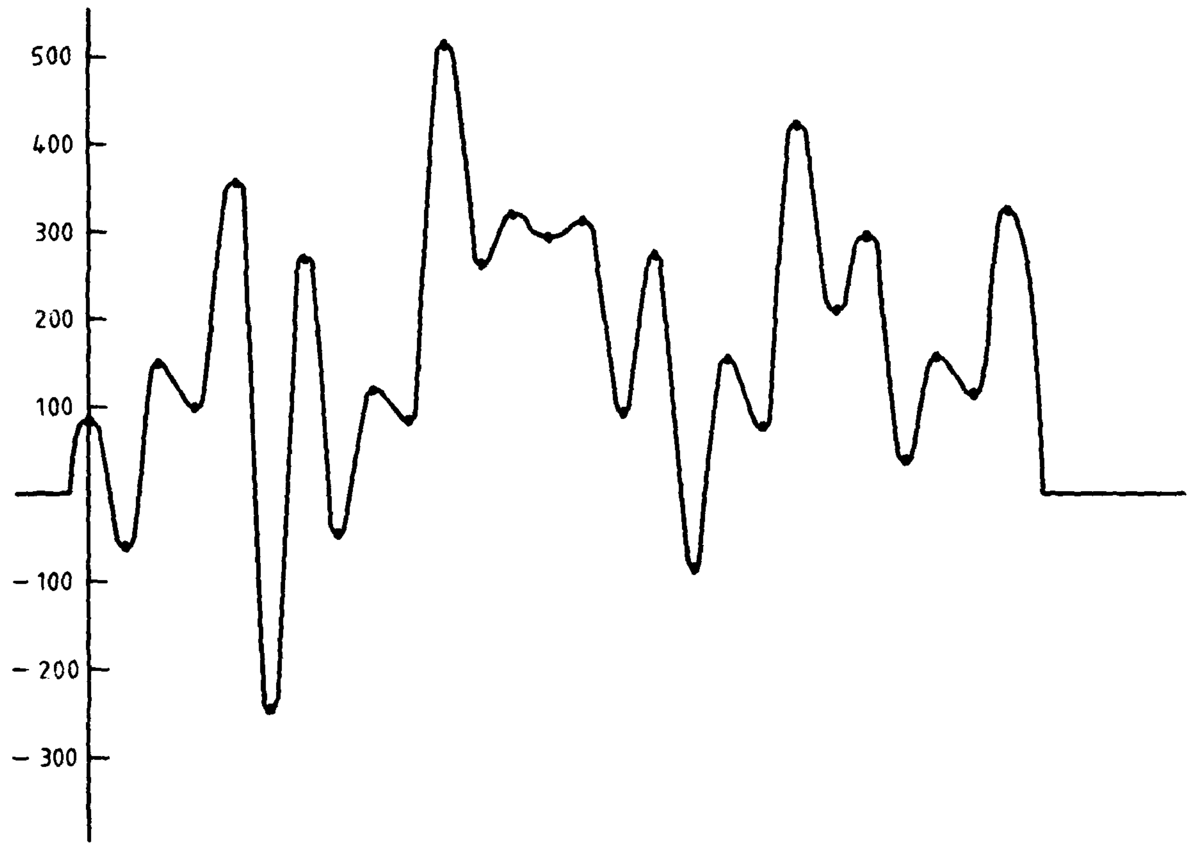


FIG. 16: TURNING POINT SEQUENCE FOR EXAMPLE 1

APPENDIX

In the following pages two sample load histories are used to demonstrate the one pass range mean pair method. In the first sequence, shown in Figure 16, the procedure is outlined step by step using a schematic turning point vector. In the second example a more realistic counting situation is proposed.

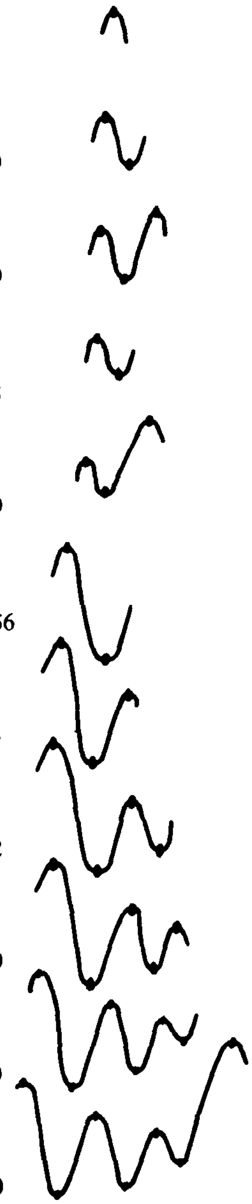
Example 1

The turning point sequence shown in Figure 16 is, in load terms:

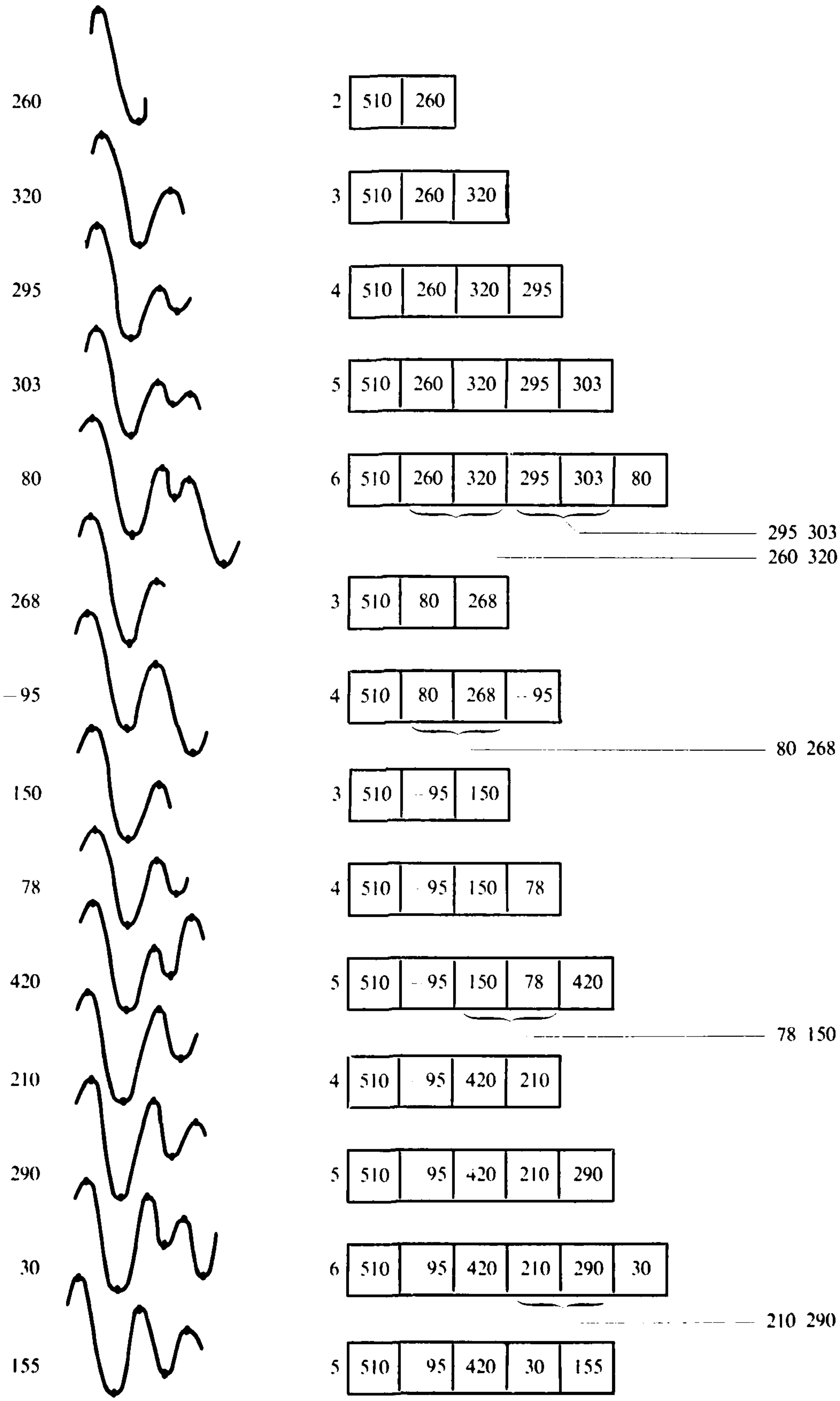
85 −60 150 98 350 −256 265 −52 120 80 510 260 320 295 303

80 268 −95 150 78 420 210 290 30 155 110 320

Using the pairing procedure as given in section two for the three point one pass method the following is obtained:



Turning Point	Cycle Sequence in Turning Point Stack	No. of Turning Points	Turning Point Stack	Range Mean Pairs
85		1	85	
−60		2	85, −60	
150		3	85, −60, 150	−60 85
98		2	150, 98	
350		3	150, 98, 350	98 150
−256		2	350, −256	
265		3	350, −256, 265	
−52		4	350, −256, 265, −52	
120		5	350, −256, 265, −52, 120	
80		6	350, −256, 265, −52, 120, 80	
510		7	350, −256, 265, 52, 120, 80, 510	80 120 −52 265 −256 350


260
2 510 260
320
3 510 260 320
295
4 510 260 320 295
303
5 510 260 320 295 303
80
6 510 260 320 295 303 80
295 303
260 320
268
3 510 80 268
−95
4 510 80 268 −95
80 268
150
3 510 −95 150
78
4 510 −95 150 78
420
5 510 −95 150 78 420
78 150
210
4 510 95 420 210
290
5 510 95 420 210 290
30
6 510 95 420 210 290 30
210 290
155
5 510 95 420 30 155

110

320

6	510	−95	420	30	155	110

7	510	−95	420	30	155	110	320

110 155

End Effect Correction: Odd number of TP's remaining — Add Nominal TP $\phi = 0$, say

ϕ

6	510	−95	420	30	320	0

Last TP is a trough ∴ Dummy TP = $+10^{30}$

10^{30}

510	−95	420	30	320	0	10^{30}

0 320

30 420

−95 510

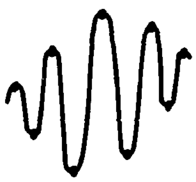
∴ Range Mean Pairs obtained by Three Point Test:

−60	85
98	150
80	120
−52	265
−256	350
295	303
260	320
80	268
78	150
210	290
110	155
0	320
30	420
95	510

Using the same procedure for a Four Point Test gives:

98	150
80	120
−52	265
295	303
260	320
80	268
78	150
210	290
110	155

with the Turning Point Stack containing the following at the end of the sequence:



85	−60	350	−256	510	−95	420	30	320

End Effect Correction: Odd number of TP's remaining ∴ Add Nominal TP $\phi = 0$ say, and pair using peak-trough counting

85	−60	350	−256	510	−95	420	30	320	0

30 320

−256	510
−60	350
−95	420
0	85

peak-trough ←

85	−60	350	−256	510	−95	420	0

Comparison of Results:

3 Point Test			4 Point Test		
98	150		98	150	Cycles which can be identified as perturbations of larger cycles i.e. range mean pairs.
80	120		80	120	
−52	265		−52	265	
295	303		295	303	
260	320	≡	260	320	
80	268		80	268	
78	150		78	150	
210	290		210	290	
110	155		110	155	
−60	85		−60	350	Cycles which cannot be identified as perturbations of larger cycles.
−256	350		−256	510	
0	320		0	85	
30	420		30	320	
−95	510		−95	420	

Example 2

The record shown overleaf contains two channels of data recorded during one flight of a monitored aircraft. The two channels, respectively normal acceleration by 100 and micro-strain at an important location, have been processed using the three point one-pass method.

Records of both sets of range mean pair data are listed. However, as pointed out previously, range mean pair tables present a more condensed and convenient form for the same data. The table of range mean pair data for channel one is included.

	LOAD FACTOR 100 n_z (g)	STRAIN AT 98E ($\mu\epsilon$)		LOAD FACTOR 100 n_z (g)	STRAIN AT 98E ($\mu\epsilon$)		LOAD FACTOR 100 n_z (g)	STRAIN AT 98E ($\mu\epsilon$)		LOAD FACTOR 100 n_z (g)	STRAIN AT 98E ($\mu\epsilon$)
1	9000.00	9000.00	101	161.21	133.50	201	111.72	31.73	301	4.41	-247.31
2	130.83	71.13	102	165.13	137.88	202	112.70	22.98	302	2.94	-248.41
3	135.24	76.60	103	163.17	134.60	203	106.82	17.51	303	0.98	-248.41
4	137.69	78.79	104	161.21	134.60	204	103.88	12.04	304	4.41	-245.12
5	135.24	79.88	105	165.62	138.98	205	105.84	4.38	305	5.88	-240.75
6	141.12	80.98	106	162.68	137.88	206	99.47	4.38	306	5.39	-240.75
7	140.63	83.17	107	163.66	138.98	207	99.47	0.00	307	8.82	-238.56
8	139.65	87.54	108	168.07	138.98	208	98.98	-7.66	308	6.37	-237.46
9	145.04	90.83	109	164.15	140.07	209	91.63	-17.51	309	10.29	-236.37
10	143.08	94.11	110	165.13	141.16	210	92.61	-21.89	310	11.27	-235.27
11	145.04	95.20	111	168.07	136.79	211	89.67	-24.07	311	9.31	-231.99
12	149.45	99.58	112	161.70	135.69	212	85.26	-28.45	312	12.25	-229.80
13	145.04	102.86	113	165.62	137.88	213	86.73	-33.92	313	14.21	-227.61
14	150.92	106.15	114	166.60	137.88	214	77.91	-45.96	314	14.70	-222.14
15	152.39	106.15	115	161.70	135.69	215	74.48	-50.34	315	16.66	-219.95
16	147.49	106.15	116	168.07	138.98	216	74.97	-56.90	316	16.66	-219.95
17	153.86	111.62	117	164.64	136.79	217	68.60	-58.00	317	18.13	-215.58
18	153.86	112.71	118	163.17	140.07	218	67.62	-64.56	318	23.52	-210.11
19	153.86	116.00	119	169.05	138.98	219	67.13	-73.32	319	22.54	-205.73
20	156.80	118.18	120	164.15	135.69	220	57.33	-82.07	320	24.01	-200.26
21	155.33	117.09	121	163.17	135.69	221	57.82	-88.64	321	28.42	-195.88
22	156.31	118.18	122	165.62	133.50	222	54.88	-93.02	322	27.44	-195.88
23	158.27	117.09	123	162.68	130.22	223	49.49	-95.20	323	30.38	-189.31
24	155.82	119.28	124	162.68	134.60	224	49.00	-105.05	324	33.81	-180.56
25	159.25	120.37	125	163.17	135.69	225	43.12	-118.18	325	34.79	-175.09
26	159.25	122.56	126	158.76	133.50	226	38.22	-122.56	326	38.71	-170.71
27	156.80	122.56	127	164.15	132.41	227	38.71	-129.13	327	43.12	-167.43
28	161.70	123.66	128	162.19	130.22	228	34.30	-132.41	328	43.61	-157.58
29	158.76	123.66	129	157.29	128.03	229	32.83	-132.41	329	49.49	-151.01
30	159.25	125.84	130	162.68	128.03	230	33.32	-140.07	330	52.43	-143.35
31	162.68	131.32	131	158.76	123.66	231	26.95	-145.54	331	55.86	-137.88
32	159.25	128.03	132	157.78	126.94	232	25.97	-148.82	332	60.76	-131.32
33	161.21	126.94	133	159.25	126.94	233	24.01	-160.86	333	63.21	-125.84
34	162.19	122.56	134	154.35	121.47	234	18.13	-166.33	334	66.64	-116.00
35	157.29	120.37	135	157.78	121.47	235	20.09	-168.52	335	71.05	-108.34
36	160.72	126.94	136	157.29	119.28	236	15.19	-173.99	336	73.01	-98.49
37	162.68	132.41	137	153.37	122.56	237	12.25	-179.47	337	79.38	-88.64
38	160.72	131.32	138	157.78	121.47	238	11.76	-184.94	338	84.77	-82.07
39	164.15	130.22	139	156.80	119.28	239	6.37	-194.79	339	88.20	-73.32
40	162.68	129.13	140	152.39	120.37	240	4.41	-196.97	340	93.59	-63.47
41	161.21	129.13	141	157.29	118.18	241	5.88	-199.16	341	95.06	-58.00
42	163.66	132.41	142	154.35	121.47	242	0.49	-204.63	342	99.47	-47.05
43	159.25	133.50	143	153.86	119.28	243	0.98	-205.73	343	105.35	-39.39
44	162.68	134.60	144	157.29	121.47	244	0.00	-212.29	344	106.82	-31.73
45	165.13	134.60	145	153.37	118.18	245	-4.90	-216.67	345	111.23	-20.79
46	159.25	129.13	146	156.31	120.37	246	-3.92	-219.95	346	117.11	-14.23
47	162.68	134.60	147	157.29	122.56	247	-5.39	-224.33	347	119.56	-4.38
48	163.66	134.60	148	153.86	122.56	248	-8.33	-227.61	348	124.46	3.28
49	159.74	131.32	149	158.27	123.66	249	-6.37	-230.90	349	129.36	10.94
50	163.66	133.50	150	156.31	119.28	250	-11.27	-234.18	350	129.85	19.70
51	160.72	130.22	151	153.86	117.09	251	-11.76	-242.93	351	135.73	29.55
52	160.72	129.13	152	157.29	118.18	252	-12.25	-241.84	352	136.22	36.11
53	163.17	133.50	153	155.33	118.18	253	-15.68	-247.31	353	139.16	41.58
54	157.78	130.22	154	155.82	124.75	254	-13.72	-248.41	354	145.04	48.15
55	161.70	129.13	155	160.72	126.94	255	-16.17	-249.50	355	144.55	52.53
56	161.21	128.03	156	157.78	123.66	256	-19.11	-254.97	356	148.47	63.47
57	158.76	130.22	157	159.74	128.03	257	-18.13	-259.35	357	153.86	70.04
58	164.64	132.41	158	162.68	130.22	258	-19.11	-261.54	358	152.88	75.51
59	162.68	137.88	159	160.23	133.50	259	-20.09	-264.82	359	157.29	84.26
60	159.25	132.41	160	163.66	130.22	260	-19.60	-265.91	360	160.23	90.83
61	165.13	131.32	161	162.19	131.32	261	-22.05	-267.01	361	160.72	97.39
62	161.21	132.41	162	159.74	128.03	262	-22.54	-270.29	362	164.64	106.15
63	162.19	136.79	163	162.68	129.13	263	-21.07	-271.39	363	165.62	109.43
64	166.11	138.98	164	158.76	130.22	264	-23.03	-275.76	364	166.60	118.18
65	163.17	136.79	165	160.72	130.22	265	-22.54	-279.05	365	171.01	126.94
66	164.15	133.50	166	164.15	130.22	266	-23.52	-272.48	366	169.54	131.32
67	165.13	135.69	167	159.25	130.22	267	-23.03	-275.76	367	173.46	135.69
68	161.21	138.98	168	160.23	130.22	268	-20.58	-275.76	368	176.40	138.98
69	166.60	140.07	169	162.19	126.94	269	-23.52	-277.95	369	174.93	146.64
70	165.62	137.88	170	156.80	125.84	270	-22.54	-277.95	370	178.36	149.92
71	162.19	137.88	171	159.25	128.03	271	-21.07	-279.05	371	178.85	151.01
72	164.15	135.69	172	159.25	126.94	272	-22.54	-276.86	372	175.91	148.82
73	162.19	135.69	173	155.82	125.84	273	-19.60	-277.95	373	180.81	152.11
74	163.66	136.79	174	159.25	128.03	274	-18.13	-275.76	374	178.36	153.20
75	165.62	137.88	175	157.78	126.94	275	-20.58	-275.76	375	179.83	157.58
76	159.74	136.79	176	155.33	129.13	276	-17.64	-279.05	376	181.30	159.77
77	164.15	135.69	177	157.29	128.03	277	-17.15	-276.86	377	177.38	157.58
78	164.15	132.41	178	152.39	125.84	278	-17.64	-275.76	378	178.36	157.58
79	159.25	130.22	179	152.88	125.84	279	-13.72	-274.67	379	178.36	156.48
80	164.15	132.41	180	155.33	123.66	280	-14.70	-275.76	380	175.42	157.58
81	162.68	133.50	181	147.49	121.47	281	-14.70	-272.48	381	178.85	160.86
82	161.21	140.07	182	147.98	116.00	282	-12.74	-275.76	382	177.87	166.33
83	167.58	140.07	183	148.47	111.62	283	-13.72	-274.67	383	176.89	164.15
84	163.66	136.79	184	140.14	102.86	284	-13.72	-272.48	384	181.79	172.71
85	164.64	140.07	185	139.16	99.58	285	-9.80	-272.48	385	178.36	175.09
86	167.09	141.16	186	138.18	95.20	286	-11.27	-269.20	386	180.32	179.47
87	163.17	141.16	187	134.75	89.64	287	-9.80	-271.39	387	182.77	179.47
88	167.09	141.16	188	135.71	84.26	288	-7.35	-269.20	388	179.34	179.47
89	167.09	138.98	189	129.85	78.79	289	-10.29	-268.10	389	182.77	180.56
90	163.66	140.07	190	128.87	74.41	290	-7.84	-268.10	390	183.26	182.75
91	168.56	137.88	191	133.28	72.22	291	-6.37	-263.73	391	180.32	183.84
92	166.11	136.79	192	126.42	64.56	292	-6.86	-260.44	392	182.28	178.37
93	161.70	136.79	193	126.42	60.19	293	-4.41	-263.44	393	180.81	176.18
94	167.09	137.88	194	126.42	58.00	294	-4.41	-259.35	394	177.87	173.99
95	163.66	138.98	195	121.03	52.53	295	-5.39	-261.54	395	181.79	179.37
96	164.15	138.98	196	123.48	50.34	296	-1.96	-257.16	396	177.87	181.65
97	167.09	136.79	197	121.03	45.96	297	-2.45	-251.69	397	179.34	178.37
98	161.70	131.32	198	117.11	42.68	298	1.47	-251.69	398	180.32	176.18
99	162.68	134.60	199	119.56	36.11	299	1.96	-248.41	399	177.38	182.75
100	165.13	134.60	200	114.17	31.73	300	-0.49	-249.50	400	183.75	186.03

401	184.73	191.53	511	155.33	120.37	621	109.27	31.73	731	105.35	[illegible]
402	187.14	191.69	512	153.36	119.24	622	111.23	32.83	732	103.88	20.79
403	192.57	199.07	513	156.80	118.18	623	114.17	31.73	733	108.78	17.51
404	191.10	202.45	514	153.86	118.18	624	110.25	31.73	734	104.37	18.60
405	195.02	204.63	515	156.80	119.28	625	113.68	31.73	735	105.84	21.89
406	199.43	212.29	516	157.78	117.09	626	112.70	32.83	736	107.80	19.70
407	198.94	215.53	517	152.39	118.18	627	110.25	33.92	737	100.94	14.23
408	202.37	219.56	518	156.80	118.18	628	114.17	33.92	738	102.90	12.04
409	206.29	222.14	519	156.80	113.81	629	111.72	30.64	739	103.88	14.23
410	206.29	228.71	520	154.35	121.47	630	108.78	26.26	740	102.90	14.23
411	214.13	234.18	521	158.76	122.56	631	113.68	29.55	741	107.31	16.41
412	211.68	238.56	522	154.35	119.28	632	110.74	33.92	742	104.86	15.32
413	212.66	239.65	523	153.86	116.00	633	113.68	40.49	743	102.41	12.04
414	219.52	241.84	524	158.27	113.81	634	117.11	38.30	744	104.37	12.04
415	216.09	241.94	525	151.90	109.43	635	112.21	31.73	745	100.94	10.94
416	220.01	244.41	526	153.37	112.71	636	113.68	28.45	746	101.92	10.94
417	223.93	252.79	527	154.84	112.71	637	113.68	30.64	747	105.35	9.85
418	220.50	253.88	528	151.41	110.52	638	112.21	33.92	748	100.94	10.94
419	225.89	254.97	529	155.33	104.34	639	116.62	38.30	749	105.35	12.04
420	224.91	256.07	530	152.89	105.05	640	113.19	33.92	750	104.37	16.41
421	221.97	259.35	531	149.94	106.15	641	112.21	29.55	751	100.94	13.13
422	227.36	260.44	532	153.96	107.24	642	115.15	27.36	752	103.88	9.85
423	225.40	258.25	533	149.45	101.77	643	111.23	31.73	753	101.92	6.57
424	224.91	261.54	534	150.43	98.49	644	112.70	36.11	754	101.92	10.94
425	229.32	262.63	535	151.41	102.86	645	116.62	35.02	755	105.35	13.13
426	224.91	263.73	536	146.51	99.58	646	110.25	29.55	756	102.90	15.32
427	226.87	265.91	537	148.96	100.68	647	113.68	28.45	757	103.88	13.13
428	228.34	263.73	538	149.94	96.30	648	114.17	31.73	758	104.86	8.75
429	224.42	263.73	539	144.06	93.02	649	109.76	31.73	759	101.92	8.75
430	227.85	263.73	540	147.98	95.20	650	113.68	30.64	760	104.37	12.04
431	228.34	264.82	541	146.51	96.30	651	112.70	29.55	761	103.88	13.13
432	223.44	267.01	542	145.04	98.49	652	110.25	28.45	762	100.45	10.94
433	228.83	267.01	543	148.96	101.77	653	114.17	29.55	763	103.88	7.66
434	225.89	265.91	544	147.49	99.58	654	110.74	29.55	764	101.43	9.85
435	222.46	264.82	545	148.96	102.86	655	111.23	27.36	765	100.94	7.66
436	225.89	264.82	546	150.92	107.24	656	113.68	30.64	766	102.41	4.38
437	221.97	263.73	547	148.96	106.15	657	109.76	28.45	767	97.51	3.28
438	224.42	267.01	548	149.94	102.86	658	112.21	29.55	768	98.98	3.28
439	226.38	262.63	549	149.45	100.68	659	113.19	30.64	769	100.45	4.38
440	220.99	263.73	550	143.57	94.11	660	108.29	27.36	770	95.55	3.28
441	223.93	260.44	551	147.00	98.49	661	113.19	28.45	771	100.45	4.38
442	223.44	260.44	552	144.55	100.68	662	111.23	28.45	772	98.00	1.09
443	219.03	261.54	553	141.12	93.02	663	110.25	29.55	773	95.06	0.00
444	222.95	259.35	554	145.04	89.73	664	114.17	30.64	774	99.47	3.28
445	220.01	258.25	555	138.67	89.73	665	109.27	29.55	775	95.55	0.00
446	217.56	257.16	556	139.16	90.83	666	109.27	26.26	776	95.06	1.09
447	220.99	258.25	557	142.59	89.73	667	113.19	28.45	777	98.49	-1.09
448	216.09	258.25	558	136.22	78.79	668	108.78	29.55	778	94.08	-5.47
449	219.52	257.16	559	135.73	74.41	669	112.70	28.45	779	95.06	-5.47
450	219.03	253.98	560	133.77	75.51	670	113.68	30.64	780	95.06	-5.47
451	215.11	251.69	561	129.85	76.60	671	110.25	29.55	781	91.63	-5.47
452	216.09	252.78	562	134.75	76.60	672	112.21	28.45	782	94.08	-7.66
453	216.58	251.69	563	132.30	71.13	673	111.23	27.36	783	93.59	-7.66
454	215.60	251.69	564	128.87	68.94	674	111.23	30.64	784	90.16	-6.57
455	217.07	248.41	565	130.34	68.94	675	115.15	32.83	785	95.06	-7.66
456	214.13	245.12	566	126.91	68.94	676	113.19	31.73	786	90.65	-9.85
457	214.13	246.22	567	126.42	66.75	677	115.15	36.11	787	90.16	-8.75
458	218.05	242.93	568	126.42	59.09	678	117.11	38.30	788	94.08	-9.85
459	214.13	240.75	569	122.99	60.19	679	114.17	41.58	789	87.71	-8.75
460	214.13	239.65	570	125.44	59.09	680	118.58	40.49	790	88.20	-10.94
461	217.07	238.56	571	124.95	63.47	681	118.58	37.21	791	91.63	-14.23
462	213.15	235.27	572	122.01	68.94	682	113.68	40.49	792	87.22	-12.04
463	215.60	235.27	573	125.93	63.47	683	119.07	41.58	793	90.65	-13.13
464	214.13	234.18	574	122.01	54.72	684	116.13	40.49	794	91.14	-12.04
465	213.64	233.09	575	119.56	52.53	685	114.17	39.39	795	88.20	-12.04
466	215.11	231.99	576	123.48	56.90	686	117.11	29.55	796	92.61	-12.04
467	214.13	235.27	577	121.03	62.38	687	110.74	24.07	797	90.16	-10.94
468	215.11	234.18	578	124.46	66.75	688	109.76	22.98	798	87.71	-12.04
469	220.50	235.27	579	124.95	58.00	689	112.70	20.79	799	93.10	-14.23
470	216.58	240.75	580	120.05	52.53	690	108.78	25.17	800	89.18	-13.13
471	219.03	240.75	581	122.01	50.34	691	109.76	28.45	801	92.12	-9.85
472	220.99	240.75	582	119.56	53.62	692	110.25	22.98	802	95.06	-10.94
473	218.54	238.56	583	119.07	54.72	693	105.35	17.51	803	89.67	-8.75
474	220.50	240.75	584	122.01	54.72	694	106.33	12.04	804	92.61	-6.57
475	219.52	240.75	585	117.11	51.43	695	104.37	10.94	805	93.59	-9.85
476	217.56	239.65	586	115.15	45.96	696	101.43	15.32	806	89.67	-9.85
477	220.01	240.75	587	117.11	41.58	697	107.31	17.51	807	96.53	-6.57
478	217.07	240.75	588	112.21	42.68	698	103.88	18.60	808	93.59	-8.75
479	216.09	239.65	589	114.17	45.96	699	102.90	16.41	809	92.12	-7.66
480	214.62	236.37	590	116.62	44.87	700	106.82	12.04	810	96.53	-5.47
481	209.23	235.27	591	110.25	42.68	701	99.96	12.04	811	93.10	-6.57
482	209.72	229.80	592	112.21	39.39	702	102.90	17.51	812	94.08	-2.19
483	209.72	227.61	593	113.19	33.92	703	106.82	16.41	813	98.00	-3.28
484	205.31	226.52	594	109.27	38.30	704	100.45	14.23	814	93.10	-4.38
485	204.33	222.14	595	114.66	39.39	705	105.35	16.41	815	96.04	-4.38
486	200.90	216.67	596	110.25	39.39	706	103.89	13.13	816	98.00	-5.47
487	197.47	214.48	597	110.25	36.11	707	102.90	16.41	817	93.59	-3.28
488	198.45	209.01	598	115.64	33.92	708	106.33	25.17	818	98.49	-3.28
489	194.06	204.63	599	111.72	30.64	709	104.37	22.98	819	96.04	-3.28
490	191.59	204.63	600	111.72	36.11	710	103.88	19.70	820	93.59	-2.19
491	190.61	200.26	601	113.19	38.30	711	105.35	6.57	821	99.96	-1.09
492	183.75	195.88	602	110.74	35.02	712	98.00	-2.19	822	95.06	-3.28
493	184.24	191.50	603	114.66	35.02	713	99.96	1.09	823	96.04	-1.09
494	181.79	179.47	604	113.19	33.92	714	101.43	8.75	824	99.47	0.00
495	176.40	178.37	605	110.74	39.39	715	98.98	13.13	825	94.57	-4.38
496	177.87	176.18	606	116.13	43.77	716	105.35	19.70	826	97.02	-1.09
497	176.40	171.81	607	115.15	40.49	717	106.33	16.41	827	97.51	-3.28
498	171.99	166.33	608	114.17	40.49	718	104.37	17.51	828	94.57	-2.19
499	171.50	159.77	609	118.58	36.11	719	109.76	20.79	829	99.47	1.09
500	167.09	155.39	610	112.21	39.39	720	105.84	19.70	830	97.02	-3.28
501	166.11	153.20	611	115.15	41.58	721	104.86	18.60	831	95.06	-3.28
502	166.60	146.64	612	117.60	41.58	722	107.80	17.51	832	97.51	-4.38
503	160.72	143.35	613	111.72	36.11	723	104.37	16.41	833	95.06	-2.19
504	160.72	138.98	614	116.62	36.11	724	105.84	19.70	834	95.55	-3.28
505	161.70	135.69	615	115.64	33.92	725	109.76	25.17	835	97.51	-3.28
506	156.80	131.32	616	110.25	35.02	726	103.88	20.79	836	94.57	-3.28
507	158.76	130.22	617	115.64	36.11	727	108.78	18.60	837	95.55	-4.38
508	155.82	123.66	618	113.19	35.02	728	107.31	18.60	838	97.02	-5.47
509	154.35	125.84	619	111.72	31.73	729	104.37	18.60	839	93.10	-4.38
510	159.25	124.75	620	115.64	32.83	730	109.27	20.79	840	97.51	-4.38

DATA FOR RANGE-PAIR COUNT CHANNEL 1 ie., N_Z X100

162.6800	157.2900
164.6400	159.2500
165.1300	157.7800
166.6000	159.2500
161.7000	167.0900
168.0700	161.7000
168.5600	161.2100
158.7600	164.1500
157.2900	162.6800
152.3900	164.1500
130.8300	169.0500
181.3000	175.4200
183.2600	177.3800
223.4400	228.8300
213.1500	220.9900
152.3900	158.7600
144.0600	150.9200
119.5600	124.9500
112.2100	117.6000
110.2500	115.6400
109.2700	118.5800
108.7800	114.1700
111.2300	116.6200
108.7800	117.1100
114.1700	108.7800
108.2900	119.0700
101.4300	107.3100
100.4500	106.3300
99.9600	106.8200
109.7600	104.3700
103.8800	109.2700
100.9400	107.3100
98.0000	109.7600
95.0600	89.6700
87.2200	99.9600
-23.5200	229.3200

CHANNEL 6: GAUGE 9BE NOTE CLOSED SEQUENCE BY 'DUMMY' 9000

131.3160	120.3730
134.5989	129.1274
134.5989	128.0331
137.8818	131.3160
138.9761	133.5046
140.0704	130.2217
141.1647	131.3160
130.2217	135.6932
118.1844	123.6559
117.0901	133.5046
71.1295	141.1647
-279.0465	-272.4807
181.6538	176.1823
183.8424	173.9937
231.9916	240.7460
113.8072	122.5616
94.1098	100.6756
93.0155	107.2414
59.0922	68.9409
52.5264	66.7523
33.9233	39.3948
36.1119	41.5834
30.6404	43.7720
28.4518	38.3005
27.3575	36.1119
26.2632	40.4891
26.2632	41.5834
20.7917	28.4518
18.6031	12.0373
10.9430	25.1689
9.8487	16.4145
6.5658	15.3202
-2.1886	25.1689
-14.2259	1.0943
-279.0465	267.0092

RANGE MEAN PAIR DATA

	-30.	-18.	-6.	6.	18.	30.	42.	54.	66.	78.	90.	102.	114.	126.	138.	150.	162.	174.	186.	198.	210.	222.	234.	246.
-30.	0																							
-18.	0	0																						
-6.	0	0	0																					
6.	0	0	0	0																				
18.	0	0	0	0	0																			
30.	0	0	0	0	0	0																		
42.	0	0	0	0	0	0	0																	
54.	0	0	0	0	0	0	0	0																
66.	0	0	0	0	0	0	0	0	0															
78.	0	0	0	0	0	0	0	0	0	0														
90.	0	0	0	0	0	0	0	0	0	2	0													
102.	0	0	0	0	0	0	0	0	0	0	5	2												
114.	0	0	0	0	0	0	0	0	0	0	0	8	1											
126.	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
138.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
150.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1								
162.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	10	0							
174.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C	0	0	2						
186.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
198.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
210.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			
222.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
234.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
246.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
258.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TOTAL NUMBER OF RANGE PAIRS = 36

RANGE PAIR TABLE FOR DATA FROM CHANNEL 1. ie., $N_Z \times 100$.

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